Waste Management 80 (2018) 397–405

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Reduction of greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs) from municipal solid waste management (MSWM) in the Philippines: Rapid review and assessment

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ARTICLE INFO

Article history:
Received 30 May 2018
Revised 3 August 2018
Accepted 22 September 2018
Available online 1 October 2018

Keywords:
Municipal solid waste management (MSWM)
Climate change
Greenhouse gases (GHGs)
Short-lived climate pollutants (SLCPs)
Black carbon (BC)

ABSTRACT

Municipal solid waste management (MSWM) is considered one of the serious environmental issues in the Philippines, with corresponding linkages to the climate change and Sustainable Development Goals (SDGs). However, methane (CH_4) linked with indiscriminate dumping of municipal solid waste has received the much attention with regard to public health and climate change. The impacts of black carbon (BC) are less documented and understood. This paper aims to review the status of MSWM in the Philippines and makes efforts to assess the scale of short-lived climate pollutants (SLCPs), including both CH_4, and BC, associated with the country's waste sector. Utilising available national level data and following a life-cycle assessment (LCA) approach, the paper offers preliminary projections of SLCP emissions resulting from present MSWM practices. In addition, it examines model mitigation scenarios based on priority actions identified within the country's national policy on waste management, Republic Act 2003 (RA 9003). Data analysis was conducted using an Emission Quantification Tool (EQT) developed by the Institute for Global Environmental Strategies (IGES) through its work under the Climate and Clean Air Coalition (CCAC) – Municipal Solid Waste Initiative (MSWI). Following a summary of key findings, the paper affirms that control of methane from disposal practices and of BC from waste collection and open burning requires urgent attention in the Philippines. Continued awareness raising, institutionalising regulatory policies on SLCPs, and further enhancing data collection and capacity building on waste-related BC emissions remain key priorities for the country.

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1. Introduction

Municipal solid waste management (MSWM) is a crosscutting issue that touches on multiple aspects of society, the environment and the greater economy. MSWM is closely associated with the numerous development goals identified under the Sustainable Development Goals (SDGs) including healthy lives, sustainable cities, poverty reduction, food and resource security, consumption and production, decent work, and climate change (UNEP and ISWA, 2015; Ljiljana and Wilson, 2017; Premakumara and Amanuma, 2018). While landfills represents the third largest source of methane (CH_4) and about 12% of total global methane emissions (GMI, 2011; U.S. EPA, 2010), MSWM has emerged as one of the major policy concerns with regard to achieving the Paris Climate Agreement, signed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015 (United Nation, 2015).

Estimations also suggest that 40% of black carbon (BC), a short-lived climate pollutant (SLCP) attributed to open burning of urban and agricultural waste, can warm the climate over relatively short lifetimes in the atmosphere (UNEP, 2011; Bond et al., 2013; UNEP and ISWA, 2015; Kutzner et al., 2018). According to the European Investment Bank (2016), BC has a warming impact on climate 1055–2020 times stronger than CO_2 over a 100-year time horizon. In view of the significant impact SLCPs have on climate change,

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https://doi.org/10.1016/j.wasman.2018.09.036
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international initiatives such as the Climate and Clean Air Coalition[1] are increasingly emphasising that mitigation of greenhouse gases (GHGs) such as carbon dioxide (CO_2) must be conducted together with near-term measures targeting SLCPs to ensure average global temperatures remain below 1.5–2 °C (UNEP and WMO, 2011; UNEP, 2011; Blackstock and Allen, 2013, World Bank, 2015; Sims et al., 2015; UNEP 2017). In addition to having a warming effect on the climate, SLCPs also comprise harmful air pollutants with negative impacts to human health, agriculture and ecosystems (UNEP and WMO, 2011). Together with open waste burning, the use of inefficient waste collection vehicles also emits BC, which as a component of fine particulate matter (PM2.5), negatively affects air quality (UNEP and WMO, 2011; UNEP, 2017). When unsustainably managed, waste generates toxins and microbes that can also significantly contaminate the ambient environment, including soil, and water (UNEP and WMO, 2011; UNEP, 2017). Climate-friendly approaches to MSWM are thus well aligned with global actions addressing GHGs and SLCP emissions, which is of growing interest in both developed and developing countries.

Against this background, more than half of the world's population presently reside in urban areas, with the figure expected to increase to 66% by 2050 (United Nations, 2014). Current trends also indicate that urbanisation combined with the overall growth of the world's population may potentially add another 2.5 billion people to urban populations by 2050, with close to 90% of the increase concentrated in Asia and Africa (United Nations, 2014). Together, rapid urbanisation and rising income levels can have a considerable effect on consumption habits, in turn driving increasing waste generation (Singh et al. 2014,2015).

In view of these challenges, addressing the downstream consequences of MSWM in developing countries remains a clear priority. Given its demographics, economic dynamism and unique policy environment, the Philippines constitutes a notable example. According to the country's latest census in 2015, the population of the Philippines comprises 100.98 million, an increase of 8.64 million compared with preceding estimates in 2010, and 24.47 million higher than 2000 (Philippine Statistics Authority, 2016). Recent waste projections also indicate that annual waste generation is expected to increase from 13.48 million tonnes in 2010, to 14.66 million tonnes in 2014, reaching 16.63 million tonnes by 2020 (DENR, 2015). Taking these figures into account, national waste collection coverage currently ranges between 30 and 100% (average 65%), suggesting that approximately 35% is improperly disposed in open areas, either through uncontrolled dumping or through burning. Moreover, it has been well documented that a large percentage of collected waste in the Philippines is often ultimately disposed in open landfills. Although the country's national policy on waste management, Republic Act 9003 (RA 9003) explicitly prohibits the operation of open dumpsites, many such dumps remain in operation, contributing to many of the environmental problems outlined above (DENR, 2015; Premakumara et al., 2014).

In this context, the Government of Philippines has identified MSWM as one of the key sectors targeted for GHG mitigation efforts under the country's National Framework Strategy on Climate Change for 2010–2022 (Climate Change Commission, 2010). Similarly, the Government of Philippines also submitted its Intended Nationally Determined Contribution (INDCs) in accordance with Decisions 1/CP.19 and 1/CP.20 of the Conference of Parties of the UNFCCC, which outlines a commitment to reduce GHG emissions 70% by 2030 relative to a baseline Business As Usual (BAU) scenario, with added reference to the waste sector (Republic of Philippines, 2015). Such consideration is important, as recent estimations have shown that the country's waste sector released approximately 11.6 million $MtCO_2e$, making up 9% of the Philippines' total GHG emissions for 2000 (Climate Change Commission, 2010; USAID, 2015). Nevertheless, SLCPs such as methane emissions associated with landfill disposal continue to receive the majority of attention with regard to waste management and climate change. The impacts of BC 2 have thus far been less documented and understood.

This paper thus aims to review the status of MSWM in the Philippines with initial estimates of both GHG and SLCP emissions (CH_4, and BC) in the country's waste sector. Utilising available national-level data and following a life-cycle assessment (LCA), the paper also offers preliminary projections of GHG and SLCP emissions associated with present MSWM practices as a BAU baseline and examines model mitigation scenarios based on the priority actions identified in RA 9003. An estimation of the GHG and SLCP emissions were calculated using the Emission Quantification Tool (EQT), which was developed in line with IPCC (2006), and other internationally recognised guidelines and emission factors. Finally, the paper summarises key findings and affirms that methane controls from landfill disposal, and of BC from waste collection and open burning require urgent attention for addressing climate change in the Philippines. Continued awareness raising, together with efforts to improve data collection on waste-related SLCP emissions remain key priorities for the country.

2. Materials and methods

2.1. Status of MSWM in the Philippines

The Department of Environment and Natural Resources (DENR) estimates that approximately 40,726 tonnes of waste was generated per day in the Philippines in 2014 with the average waste generation rate of 0.40 kg/capita/day (DENR, 2015) of which 26,472 tonnes/day (about 65%) was collected and transported to final disposal sites. Such estimations also project that annual waste generation is expected to increase from 14.63 million tonnes in 2014 to 16.63 million tonnes by 2020 (DENR, 2015). In terms of total waste quantities, residential or household waste comprises the bulk (56.7%) of MSW while the remainder is produced from commercial, including markets (27.1%), public establishments (12.1%) as well as industry and the manufacturing sector (4.1%). (See Fig. 1 (left). In addition, data in Fig. 1 (right), shows that average biodegradable wastes comprise about half of MSW (52.27%), with recyclable waste accounting for almost a third (27.87%); the balance includes special wastes, which consist of household and healthcare waste, waste electrical and bulky waste (1.93%) and residuals (17.98%). Total organic waste includes food waste (45.05%) and yard waste (7.22%), while recyclable waste includes plastics (10.56%), paper and cardboard (8.61%), glass (2.43%) metal (4.22%), textiles (1.61%) rubber and leather (0.44%).

As the Philippines has continued to make efforts to decentralise its public administration system, policy actions at the national level have sought to encourage more localised approaches to MSWM. In 2001, the government enacted its *Ecological Solid Waste Management Act*, widely referred to as Republic Act No. 9003 (RA 9003). RA 9003 serves as a national policy and regulatory framework for introducing a systematic and comprehensive approach to solid waste management. It seeks to ensure the protection of public health, address negative environmental impacts and support economic development through the introduction of best practices including with regard to waste segregation, collection,

[1] The Climate and Clean Air Coalition is "a voluntary partnership of governments, intergovernmental organizations, businesses, scientific institutions and civil society organizations committed to protecting the climate and improving air quality through actions to reduce short-lived climate pollutants." http://ccacoalition.org/en/content/about.

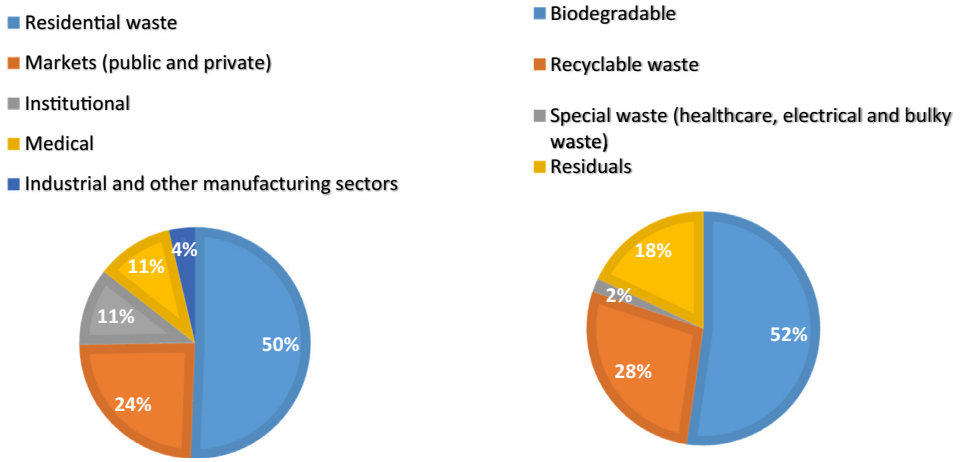

Fig. 1. Percentage contribution of the various sources of MSW (left) and waste composition (right) (Source: DENR, 2015).

transport, recycling, treatment and disposal (Congress of the Philippines, 2000). With a view towards establishing an integrated MSWM system across local government units (LGUs), RA 9003 further mandates the establishment of material recovery facilities (MRFs) in all barangays, the lowest-level of administrative and political system in the country, based on 3R (reduce, reuse and recycle) principles. The Act also bans open burning and dumping in favour of sanitary landfills and requires the diversion of at least 25% waste away from landfill sites.

Although RA 9003 presents a major breakthrough for steering the country's waste management policies and regulations towards a more climate-friendly approach, implementation at the LGU level is patchy and limited. According to the Department of Environment and Natural resources (DENR), a compliance of waste segregation at source ranged from 43% to 100% based on validations conducted by National Solid Waste Management Commission (NSWMC) Secretariat (DENR, 2015). Urban centres report higher coverage rates and collection frequencies in comparison to rural and upland areas. A number of LGUs have also introduced composting in order to meet the mandatory organic waste diversion requirements set out by law, adopting both small-scale (compost pits, tire towers, coconut shell stacks, bottomless bins, clay pots and plastic sacks) and large-scale methods (windrows (by turning, passive aeration, active aeration and static piles), in-vessel (e.g., agitated beds, composting silos and rotating drum bioreactors), as well as through vermi, or worm composting). However, composting is still being piloted in many areas and locating complete and accurate data on total composting volumes across the country remains difficult. (DENR, 2015).

In addition, recycling also occupies an important role in achieving mandatory waste diversion requirements as recognised under RA 9003. The Act offers guidelines on the establishment and operation of buy-back centres and material recovery facilities (MRFs), as well as provides an inventory of markets, including definitions for eco-labelling of recyclable products. Recyclables, particularly those with high commercial value such as paper, scrap metals and plastics are typically sold to junk dealers, consolidators and recyclers by households and accumulated recyclables from MRFs are often delivered to junkshops. Recovered materials sold to local junkshops pass through a supply chain of intermediaries and wholesalers located across the industrial sector, primarily outside the Philippines, however currently no accurate data is available.

RA 9003 also prohibits the establishment and operation of open dumpsites or any practice or method of disposal involving the use of open dumps. Open dumpsites were required to be converted into controlled dumps as a temporary and remedial measure up

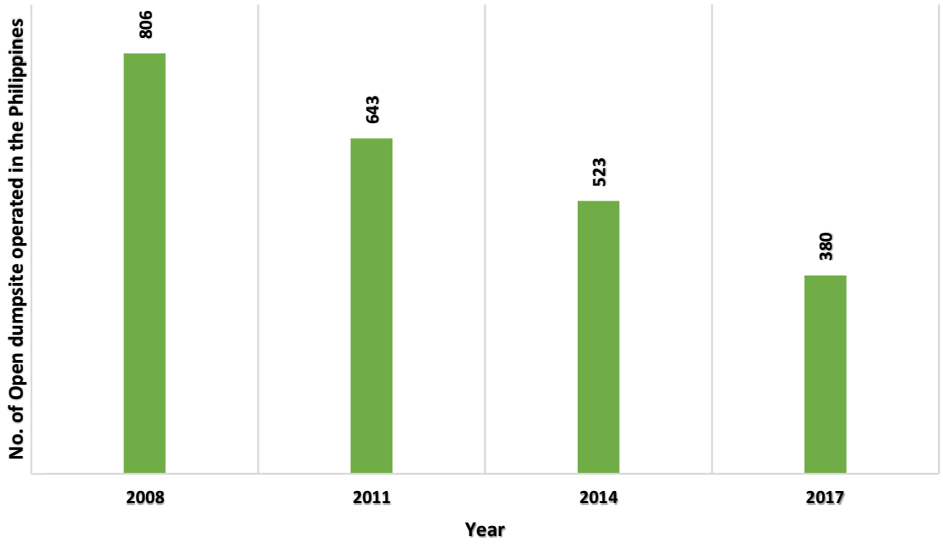

Fig. 2. Number of open dumpsite operated in the Philippines (Source: DENR, 2015; 2018).

Fig. 3. GHGs/SLCPs emissions from all the activities related to waste management (Source: Compiled by Authors, 2018).

until the year 2006. As shown in Fig. 2, although the number of open dumpsites across the country has decreased over time, many are yet to be closed or converted into controlled and/or sanitary facilities (DENR, 2015).

2.2. Methodology

Evaluating the status of MSWM and its negative impacts in relation to GHGs and SLCPs emissions, the paper adopted a life-cycle assessment (LCA) methodology for estimating climate impacts of the Philippine's waste sector. LCA is a well-established tool for GHGs accounting and decision-making in waste management processes (Christensen, 2009; Menikpura et al., 2012; Singh et al., 2014; Thomsen et al., 2017; Neri et al., 2018). LCA approaches to waste management include an upstream-operating-downstream (UOD) generic framework that allows the system boundary to be specified for a particular measurement (Gentil et al., 2009; Menikpura et al., 2012; Lazarevic, 2018). For instance, whereas indirect upstream factors can account for emissions associated with energy and material inputs, direct operating emissions are taken to include all unit operations of waste management, from collection and transportation through recycling to treatment and disposal (Menikpura et al., 2013; Thomsen et al., 2017). Likewise, LCA methods allow for the inclusion of downstream benefits resulting from materials recycling, organics recycling and energy recovery, which has potential for displacing the use of virgin materials and energy, and thus GHG emissions associated with their production and distribution. LCA methods can also be extended further to include the benefits of waste prevention and reduction, such as the benefits of avoiding the manufacture of products that would ultimately end up as waste. Such indirect downstream benefits may include savings and emissions from energy substitution, material substitution and carbon binding (sequestration). For purposes of this study, system boundaries encompass all stages of the waste management system from waste collection, transportation to its final disposal as well as potential resource recovery (outlined in Fig. 3).

An Emission Quantification Tool (EQT) developed by the Institute for Global Environmental Strategies (IGES) through its involvement in the Climate and Clean Air Coalition (CCAC) – Municipal Solid Waste Initiative (MSWI) was used for estimations of GHGs/SLCPs. This tool has been designed in line with IPCC (2006) and other internationally recognised guidelines and emission factors. Mathematical formulas have been developed to quantify gross emissions, avoided emissions (savings) and the net emissions from individual treatment methods considering all the phases of the life cycle, as outlined in Table 1. Since 2015, the EQT has been used for rapid assessment of the SLCPs from MSWM in various countries and cities across the Asia-Pacific region (IGES, 2018; CCAC-MSWI, 2018).

Table 1
Calculation factors used by IGES EQT.

(a) Calculation of Gross GHG/SLCPs emissions from individual treatment method throughout the life cycle	**GHGs/SLCPs Gross emissions** = Emissions from Transportations + Emissions from operations + Emissions from Treatment/Final disposal
(b) Calculation of GHGs/SLCPs avoidance/savings potential from individual treatment method	**GHGs/SLCPs Avoidance/savings** = GHGs/SLCPs avoidance through energy recovery + GHGs/SLCPs avoidance through material recovery
(c) Calculation of overall climate impact or benefit of a waste management system will depend on net GHGs/SLCPs, accounting for both emissions and indirect, downstream GHGs/SLCPs savings potentials across the life cycle. Net GHGs/SCLPs emissions from individual treatment methods	**GHGs/SLCPs Net emissions** = GHGs/SLCPs Gross emissions – GHGs/SLCPs Total savings/avoidance
(d) Calculation of net GHGs emissions from generated waste in the Philippines	**Net GHGs emissions from generated waste (kg CO_2-eq/tonne of generated waste)** = total GHGs emissions from transportation (kg CO_2-eq/tonne of waste) + % of waste use for composting/100 × net GHGs emissions from composting (kg CO_2-eq/tonne of organic waste) + % of waste to recycling/100 × net GHGs emissions from recycling (kg CO_2-eq/tonne of recyclables) + % of waste to open dumping/100 × GHGs emissions from open dumping (kg CO_2-eq/tonne of mix waste) + % of waste to control disposal/100 × GHGs emissions from control disposal (kg CO_2-eq/tonne of mix waste) + % of waste to sanitary landfilling/100 × net GHGs emissions from landfilling (kg $_{CO2}$-eq/tonne of mix waste) + % of waste uncollected/100 × GHGs emissions from uncollected waste (kg CO_2-eq/tonne of mix waste)

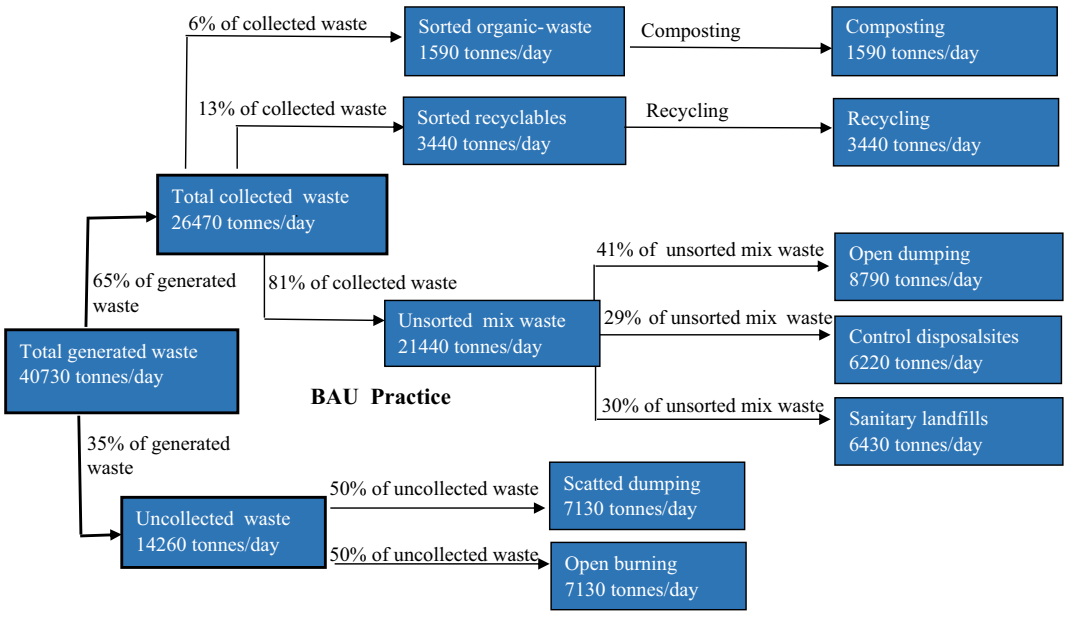

Fig. 4. Current Status/Business as Usual (BAU) Practice of MSW management in the Philippines.

Emission factors used by the EQT were considered by way of an extensive literature review (IPCC, 2006; EEA, 2016; DENR, 2018), and other required data was gathered through direct interviews and questionnaire surveys. A number of field visits and focus group discussions were also carried out during the period of August 2017 and April 2018 in the Philippines in order to collect primary and secondary data in the Philippines. Following these initial investigations, a waste flow analysis was conducted at national level in the Philippines to establish a baseline for BAU practices (see Fig. 4), examining current GHGs/SLCPs emissions associated with ongoing waste management operations. It was estimated that about 19% of collected waste is being separated for resource recovery (6% for composting and 13% for recycling) with remaining mixed waste disposed of in open dumps, through controlled disposal, or sanitary landfills (USAID, 2015), see Fig. 4.

Although there is no optimal treatment system appropriate for all waste fractions in terms of climate change mitigation, it is well established that integrated solid waste management (ISWM) approaches often represent the most sustainable and climate-friendly mode of operations (Premakumara et al., 2011; Marchi et al., 2017; Maccanti et al., 2017; Premakumara and Amanuma, 2018). In applying the EQT, this paper analyses several potential options for improvements in view of their current applicability and policy relevance, identifying three scenarios (see Table 2) for the promotion of climate-friendly MSW management in the Philippines:

- Scenario I – considers an improved waste collection rate with separation of a higher percentage of organic waste and recyclables for resource recovery. It aims to examine the mitigation impact from improved waste collection rate (up to 80%) followed by organic waste separation for composting and diversion of clean recyclables for recycling. The separation of organic waste for composing (40% of collected waste) and recyclables (15% of collected waste) from collected mixed waste were assumed as reasonable targets, with the remaining mixed waste sent to disposal facilities at the rates of 34% for open dumping, 24% for controlled disposal and 42% for sanitary landfill, respectively. The 20% of generated waste is uncollected which is assumed to be dumped indiscriminately (50%) or burned openly (50%).
- Scenario II – takes into account an improved waste collection rate and the termination of open dumping associated waste disposal. It was designed to examine the emissions reduction potential from further improvement of waste collection rates (up to 90%) and termination of open dumping practices while at the same time expanding sanitary landfill disposal. Based on this analysis, terminating open dumping would result in 20% of unsorted-collected waste disposed in controlled disposal sites with the remaining 80% of collected waste disposed in sanitary landfills. 10% of generated waste is uncollected which is assumed to be dumped indiscriminately (50%) or burned openly (50%).
- Scenario III – presents the ideal condition: 100% waste collection and termination of both open dumping and controlled disposal. It was assumed that 100% of unsorted, mixed waste collected by the cities is disposed in sanitary landfills and 60% of generated methane is recovered and used for energy purposes (cooking and heating). This option allows for a comparable amount of fossil fuel consumption, and associated GHGs/SLCPs emissions, to be avoided that might otherwise occur.

For purposes of assessment and comparison between each scenario, the unit of analysis considered in this study was "GHGs/SLCPs emissions per tonne of generated waste". Major GHGs (CO_2, CH_4, N_2O) and SLCPs (CH_4, BC) emitted from actual and intended scenarios were estimated. GHGs emissions have been presented as kg to CO_2 equivalent. IPCC recommended Global Warming Potential (GWP) 100 year values have also been utilised for aggregating net climate impact of different types of GHGs (e.g. methane biogenic CH_4-28; fossil methane CH_4-30; nitrous oxide N_2O-265). GWP value of BC has not yet been finalised yet and as such, net BC emissions impacts are estimated and presented separately. The calculation methodology applied in this study considers IPCC emission factors to derive precise mathematical formulas for GHG/SLCP quantification.

Lastly, the estimation of net GHGs/SLCPs emissions from individual treatment methods can be used to inform decision-making towards the selection of more climate-friendly waste management options. As highlighted above, in order to measure overall progress under each individual scenario, net GHGs/SLCPs emissions are calculated based on "per tonne of generated waste" aggregating

Table 2
Waste Management (WM) options in BAU and different scenarios.

WM Options	BAU*	Scenario I**	Scenario II***	Scenario III****
Composting	✔	✔	✔	✔
Recycling	✔	✔	✔	✔
Open-dumping	✔	✔	✗	✗
Control disposal sites	✔	✔	✔	✗
Sanitary landfills	✔	✔	✔	✔
Scatted dumping	✔	✔	✔	✗
Open burning	✔	✔	✔	✗

Collected waste Uncollected waste

✔ Available ✗ Unavailable

*65% of total generated waste is collected and 35% remains as uncollected waste.
**80% of total generated waste is collected and 20% remains as uncollected waste.
***90% of total generated waste is collected and 10% remains as uncollected waste.
****100% of total generated waste is collected.

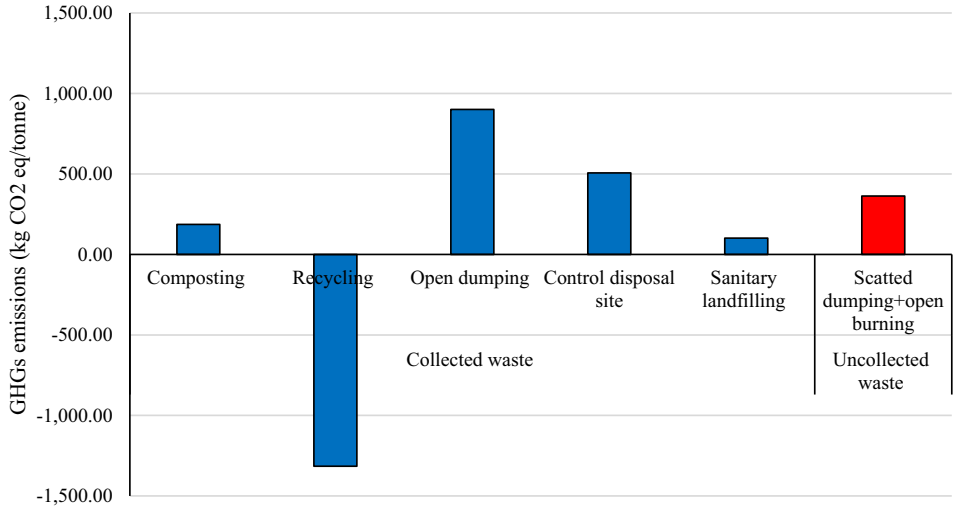

Fig. 5. GHGs emissions from treatment methods associated with current/BAU practices.

potential impacts from all the treatment methods in each particular scenario to allow for a cross-comparison and identification of options with the greatest mitigation potential.

3. Results

3.1. GHGs/SLCPs emissions from Current/BAU practice in the Philippines

Fig. 5 presents results of calculations with consideration of GHGs emissions associated with current waste management practices or BAU. The results indicate that net GHGs emissions associated with existing composting practices amounted to 186 kg CO_2-eq per tonne of organic waste. Recycling and recovery of materials would further help to avoid GHGs emissions associated with virgin production. Negative values based on GHG savings were calculated as a net impact of recycling, totalling approximately 1315 kg of CO_2-eq per tonne for mixed recyclables.

In addition, open dumping was found to produce the highest methane emissions, followed by controlled disposal sites and sanitary landfills, at the rate of 901 kg of CO_2-eq per tonne, 507 kg of CO_2-eq per tonne and 102 kg of CO_2-eq per tonne, respectively. Anaerobic conditions in deeper areas of open dumpsites (>5 m)

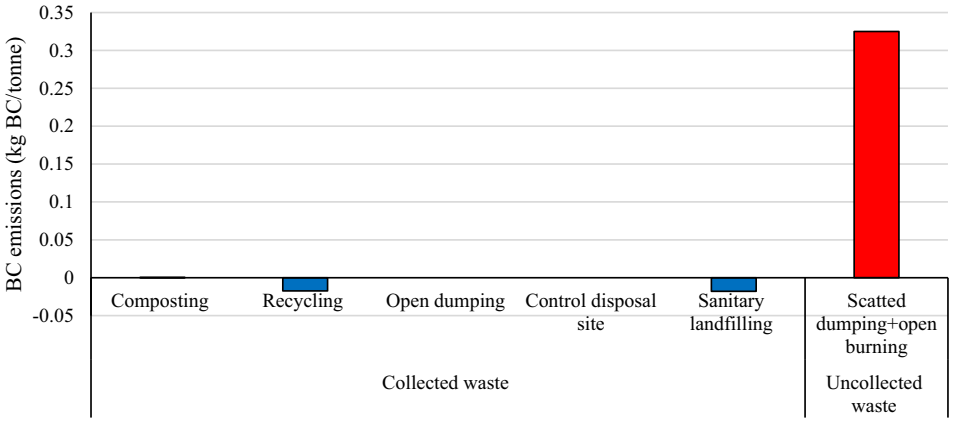

Fig. 6. BC emissions from Current/BAU Practice.

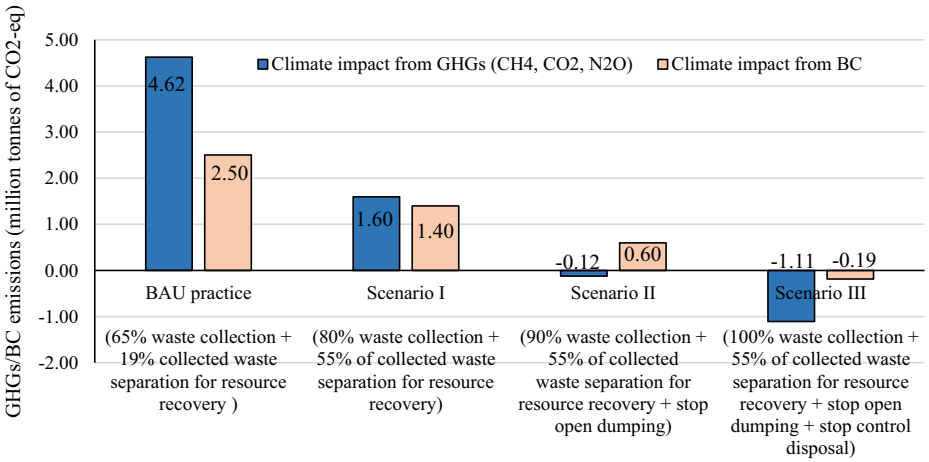

Fig. 7. GHGs/SLCPs Mitigation Potentials Associated with Annually Generated Waste Resulting from Implementation of Appropriate Technologies.

showed the greatest potential for generation of methane and were linked with the highest rates of GHG emissions. At the same time, landfill gas recovery for energy production from sanitary landfills was also found to have strong potential for emission reductions.

The results also identified that for GHG emissions associated with uncollected waste, each tonne of uncollected waste was determined to emit 363 kg CO_2-eq/tonne of waste, mainly due to methane emissions resulting from scattered open dumping and CO_2 emissions linked with open burning. Net GHGs emissions from generated waste were estimated by considering GHG mitigation potential from existing disposal practices of 'collected waste' and 'uncollected waste', amounting to 311 kg of CO_2-eq/tonne of generated waste. Based on this figure, total GHGs emissions stemming from annually generated waste in the Philippines (40,730 tonnes/day × 365) is equivalent to 4.62 million tonnes of CO_2-eq.

Similarly, Fig. 6 presents BC emissions from existing composting, recycling, disposal options as well as from uncollected waste. The results indicate that BC emissions associated with composting is minimal (<0.001 kg/tonne of waste) given that composting does not consume significant amounts of fossil fuel. Recycling would substantially contribute to the avoidance of BC emissions through material recovery, with estimated net savings amounting to 0.017 kg per tonne of mixed recyclables. Energy recovery from sanitary landfills result in additional BC mitigation benefits, amounted to 0.018 kg per tonne of waste. However, as seen in Fig. 6, the highest amount of BC emission occurs from open burning of uncollected waste, amounting to 0.33 kg per tonne. Aggregating the impacts of individual treatment methods, estimated net BC emissions potential amounted to 0.11 kg BC/tonne of generated waste. Based on this per tonne calculation, BC emissions from annually generated waste in the Philippines (40,730 tonnes/day × 365) comprises a total of 1628 tonnes. Although this represents relatively low figure in terms of overall scale, the ultimate climate impact resulting from BC reductions is significant when expressed as a CO_2 equivalent. For instance, when considering the approximate average GWP value of BC (1538 kg CO_2-eq/1 kg of BC) published by European Investment Bank (2016), the estimated climate impact of BC from BAU scenario associated with annually generated waste in the Philippines comprises 2.50 million tonnes of CO_2-eq.

3.2. A Comparative analysis of BAU practice and intended scenarios

Total GHG and BC emissions generated from BAU practice and intended scenarios based on the enactment of mandates under RA 9003, which includes expanding waste collection service, promoting resource recovery, composting and terminating open dumping, are presented in Fig. 7. The results identify that, when compared to BAU practices, 65% of GHGs can be avoided by introducing the policy directions proposed in Scenario I. This includes increasing waste collection rates up to 80% and promoting waste segregation practices that enhance current separation rates, with 40% for composting and 15% for recycling of collected MSW, respectively. Moreover, GHG avoidance rates can be further

increased as high as 103% by introducing the policy directions set out by Scenario II; that is, increasing waste collection rate by 90%, continuing resource recovery (composting and recycling) and eliminating open dumping. In other words, if the Philippines can move forward with implementing Scenario II, high net GHG savings are likely to be achieved from MSW management. However, if the country can effectively follow the policy directions outlined in Scenario III— the ideal situation, with 100% waste collection rates, termination of open dumping and controlled disposal practices and the expansion of sanitary landfilling sites, along with waste separation for resource recovery—GHG mitigation potential amounts to a reduction of GHGs by 124% in comparison to BAU practices. Taken together, the data suggests that such an integrated system has the ability to serve as a net carbon sink.

Similar to GHGs emissions, BC emission from annually generated waste has been converted into million tonnes of CO_2-eq in order to compare with the ultimate effect of GHG emissions from each scenario, in line with Fig. 7. BC mitigation potentials from Scenario I, Scenario II, and Scenario III relative to the BAU practice is 44%, 76% and 107% respectively. 100% waste collection, maximum resource recovery though waste separation and termination of both open dumping and control disposal practices results in a net BC saving potential in Scenario III. Ultimately, implementing a national programme focused on increasing waste collection rates and scaling up interventions targeting the open burning of waste remains critical for reducing BC emissions in the waste sector.

4. Discussion and conclusions

The Philippines is currently spearheading several national initiatives to improve MSWM whilst mainstreaming climate considerations into existing waste management policies, plans and actions. MSWM has also been identified as one of the priority areas for action in the country's INDC. However, these activities are mainly focused on GHG mitigation and methane emissions from waste treatment options. The results of this study also confirm that promoting resource recovery from waste would make an important contribution towards achieving national GHG mitigation targets. Indeed, GHG emissions associated with existing BAU composting and recycling practices include 186 kg CO_2-eq per tonne of organic waste and −1315 kg of CO_2-eq per tonne for mixed recyclables respectively. The final disposal stage of waste management in the Philippines generates the largest percentage of methane emissions and thus needs to be identified as a primary target for intervention. According to the results, open dumping was found to produce the highest methane emissions (901 kg of CO_2-eq per tonne). Transforming from open disposal to controlled disposal sites and sanitary landfills, the GHG emission can be reduced up to 507 kg of CO_2-eq per tonne and 102 kg of CO_2-eq per tonne, respectively. All in all, the estimated GHG emission from existing waste management amounted to 4.62 million tonnes of CO_2-eq from annually generated waste in the Philippines.

In contrast, open burning of uncollected waste is a main driver of BC emissions, amounting to a total of 1628 tonnes from annually generated waste in view of BAU practices. The total emissions of BC from waste burning and fossil fuel consumption for operational activities are two orders of magnitude less than the methane generated from waste under BAU practice in the Philippines, however, as discussed BC has much higher GWP in terms of CO_2 equivalent, across a 100 years time horizon. Indeed, when considering the approximate average GWP value of BC published by European Investment Bank (2016), the estimated climate impact of BC from BAU scenario associated with annually generated waste in the Philippines comprises 2.50 million tonnes of CO_2-eq (approximately 35% of overall climate impact under BAU practices). However, potential mitigation benefits resulting from addressing SLCPs, including BC, are not widely understood and have yet to be considered in climate policy and planning. In sum, these results underline the critical importance of identifying policy and actions to address both GHG and SLCP in the Philippines. This can be achieved by local implementation of RA 9003 focusing on improving waste collection, terminating waste burning, and promoting maximum resource recovery (composting and recycling) including by encouraging waste separation and restricting open dumping and control disposal practices as described in Scenario III.

SLCP reduction measures can be accommodated both through strategic planning and selection of appropriate technology while making efforts to terminate conventional disposal practices. As such, a well-designed, integrated waste management system represents an important means of implementation for achieving climate-change mitigation targets in the Philippines. Overall, these findings highlight the need for developing a national framework aimed at addressing SLCPs from MSWM, together with its timely and necessary application. Successful planning and implementation of such a project involves consideration of the following:

(i) Awareness gaps about SLCPs among key stakeholders,
(ii) Data and analytical challenges associated with quantifying emissions reductions, potentials and co-benefits,
(iii) Strategic entry points for institutionalising a SLCP-reduction agenda into existing policy and decision-making processes, including through the establishment of an intergovernmental oversight body, and
(iv) Opportunities for scaling up means of implementation, such as through adequate, predictable and sustainable financing for appropriate technologies and capacity building.

Acknowledgments

The authors would like to acknowledge Climate and Clean Air Coalition (CCAC) and Ministry of Environment, Japan (MOEJ) for funding this project. The authors also thank all who are joined the consultative workshops and provided relevant information. Special thanks go to three anonymous reviewers for their valuable contribution to improve the manuscript.

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